Reservoir Implications of Facies and Diagenetic Variability in an Oolitic Grainstone: Pleistocene Miami Oolite*

Paul (Mitch) Harris[1] and Sam Purkis[1]

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[1]CSL - Center for Carbonate Research, University of Miami, Department of Marine Geosciences, Miami, Florida
(pmitchharris@gmail.com)

Abstract

The Miami Oolite (MO) of South Florida is representative of a grainstone-rich reservoir layer (high-frequency sequence) that has been surficially karsted (eogenetic karst), and therefore may be considered an analog for subsurface examples with "high" matrix porosity-permeability and localized touching-vug porosity. The deposit can potentially serve to illustrate heterogeneity in this type of reservoir, as imparted by facies changes and early meteoric diagenesis.

The MO displays the preserved morphology of a fossilized ooid sand body, even though it has been subaerially exposed in a tropical climate since its deposition during the last interglacial highstand – Marine Isotope Stage 5e. The depositional motif is one of a dip-oriented tidal bar belt of shoals and shallow channels fronted by a strike-oriented barrier bar. The barrier bar comprises cross-stratified grainstones and locally bioturbated grain/packstones, whereas the tidal shoals and channels are more commonly bioturbated grain/packstones. Surficial karst features (dolines and stratiform caves) have been added during the ~120 ky of subaerial exposure.

Since the MO is the uppermost portion of the Biscayne Aquifer, a rich understanding of fluid flow through the deposit exists and sheds valuable insight to the larger-scale permeability patterns and reservoir implications of facies and diagenetic overprint. The pore system comprises matrix porosity (interparticle and separate vugs) and touching-vug macroporosity that is commonly ichnologically influenced (associated with burrowed [*Ophiomorpha*] intervals). GPR, well, and flow-test data indicate that matrix porosity provides most of the groundwater storage, whereas the various types of touching vug macroporosity account for the majority of flow. The dolines and shallow caves seem to be sufficiently spaced to prevent direct connection, with the result that they are less important in terms of regional flow than the prevailing pore system.

An important "So What" from the observations of the MO reported here is that a depositional facies (burrowed intervals) has directed early-stage dissolution (creating touching-vug macroporosity) to produce the stratiform high-permeability zones that dominate flow at the larger

scale. Thus, a profound implication for analogous grainy, karsted reservoirs is that a fundamental understanding of depositional facies variation remains critical for characterizing reservoir quality and performance, even in cases of substantial diagenetic overprint.

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Reservoir Implications of Facies and Diagenetic Variability in an Oolitic Grainstone – Pleistocene Miami Oolite

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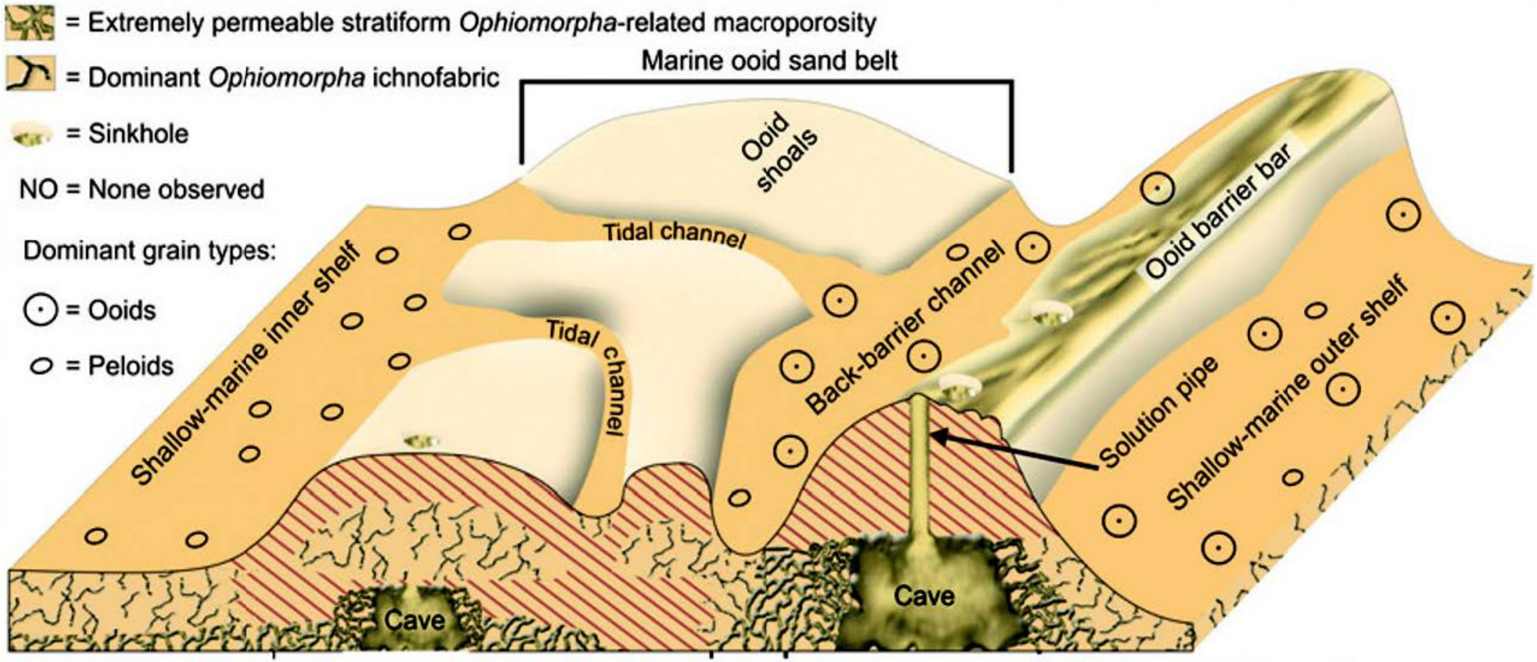
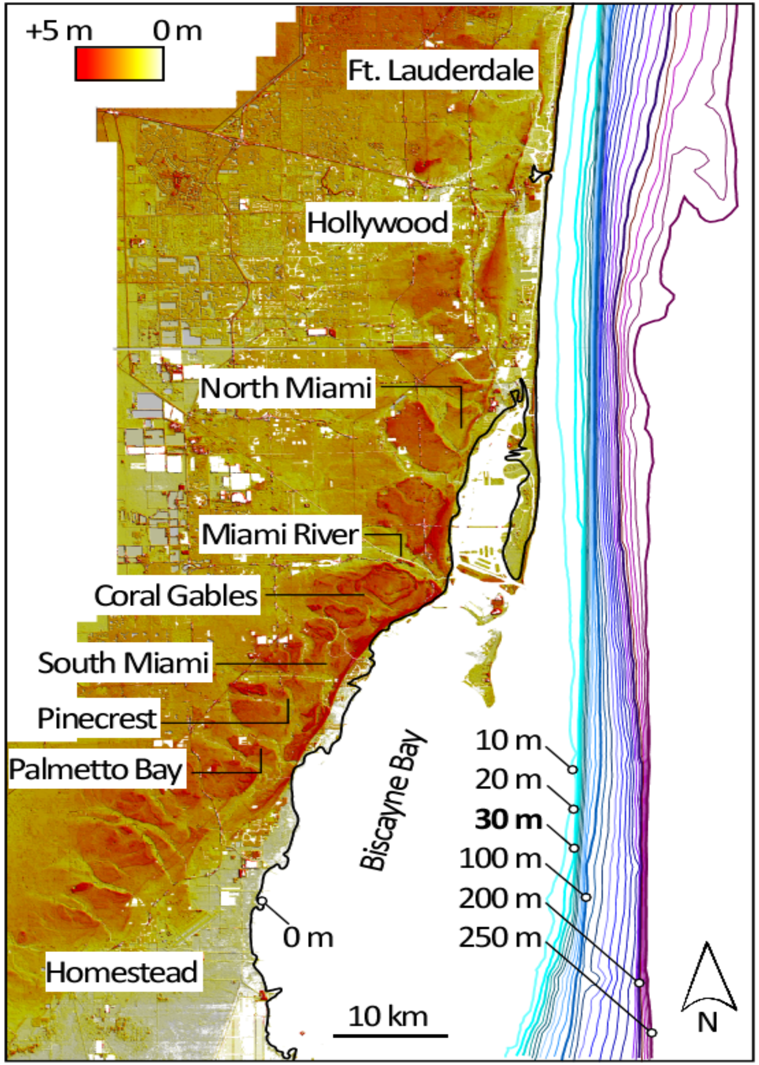


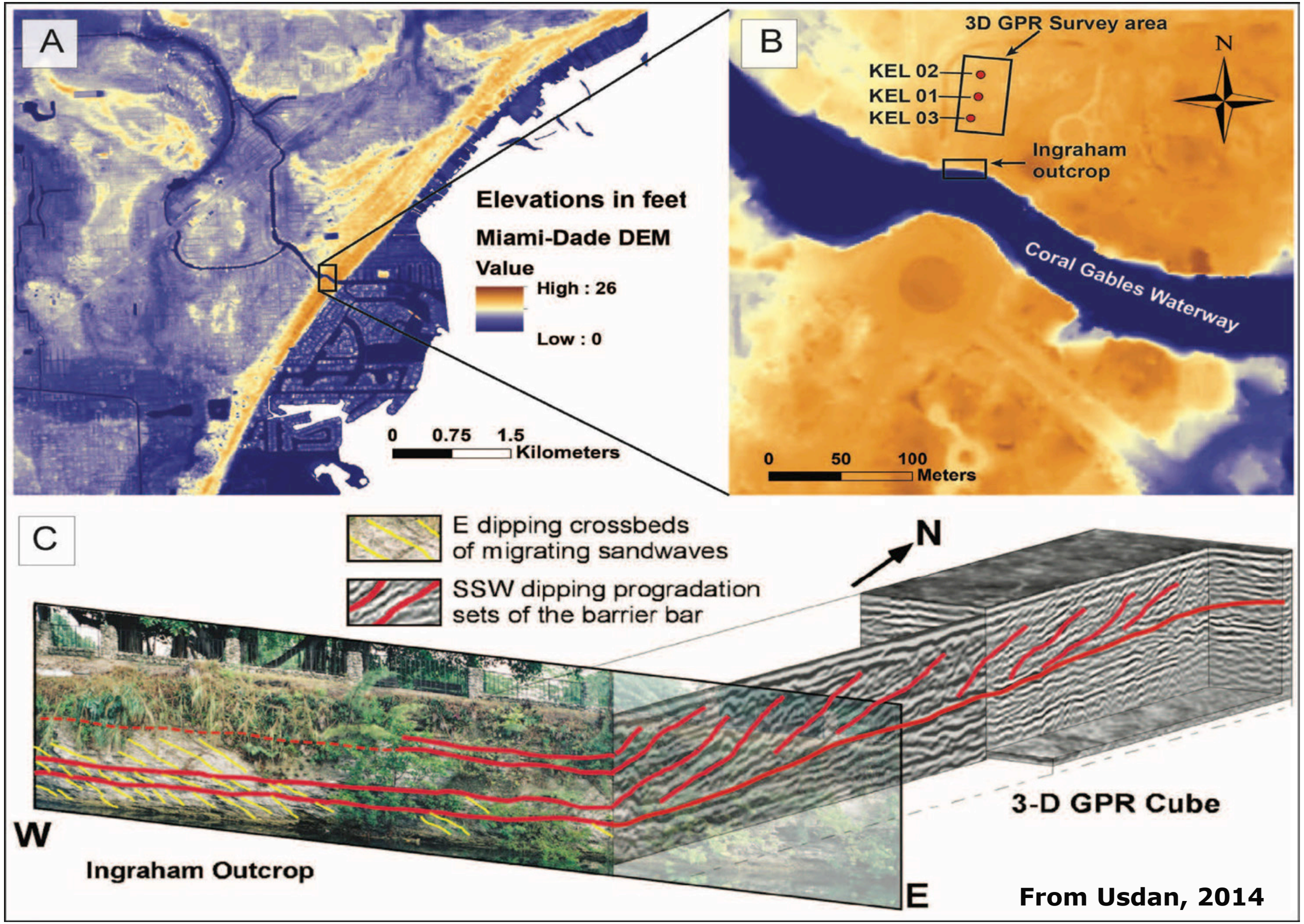


Miami Oolite Sand Body

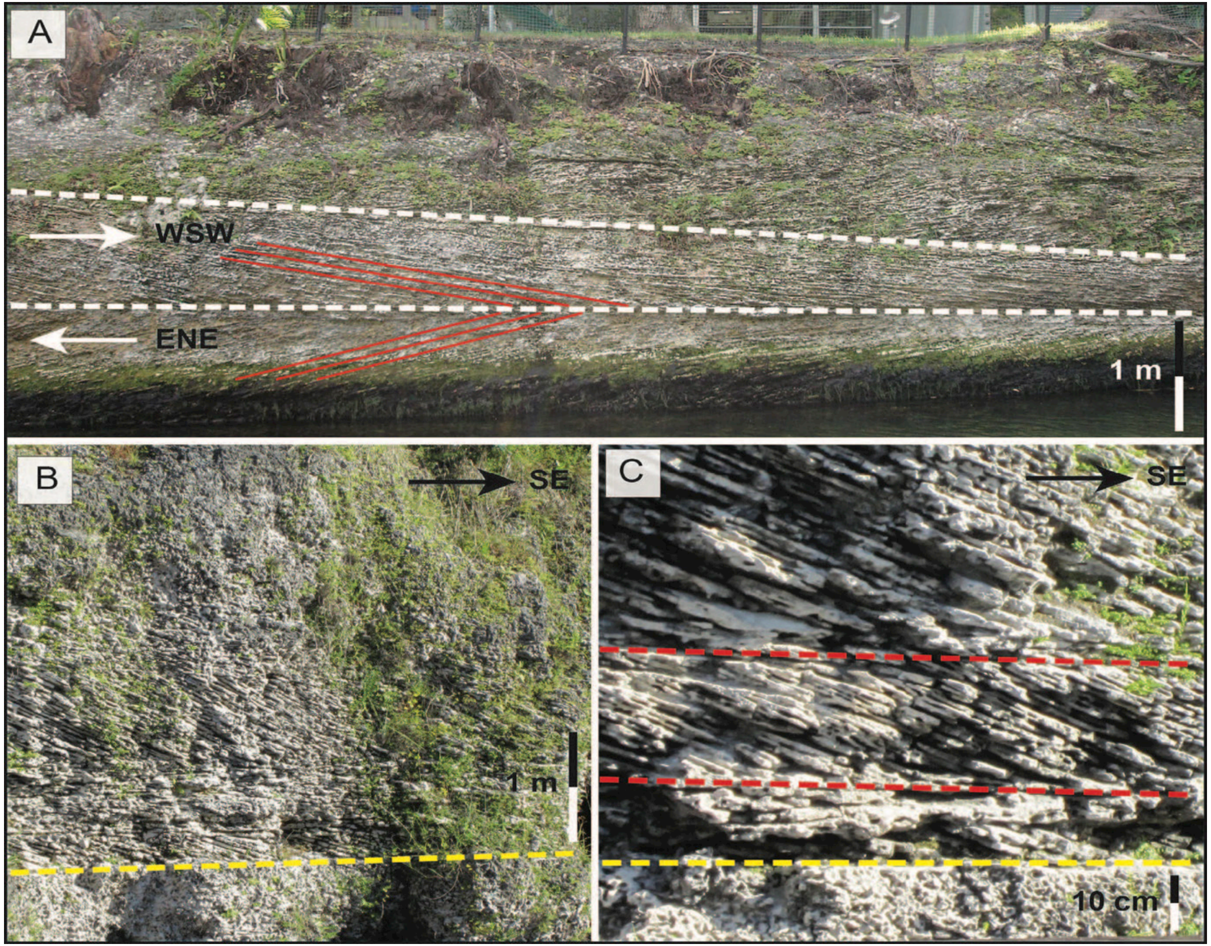
- The Miami oolite is comparable to Modern analogs from GBB in scale and internal morphology.
- The depositional motif is one of a dip-oriented tidal bar belt of shoals and shallow channels fronted by a strike-oriented, southerly long-shore current-formed barrier bar.
- The barrier bar comprises cross-stratified grstns and locally bioturbated grstns/pkstns, whereas the tidal shoals and channels are more commonly bioturbated.

From Purkis and Harris, 2017

Depositional Facies – Cross Bedded

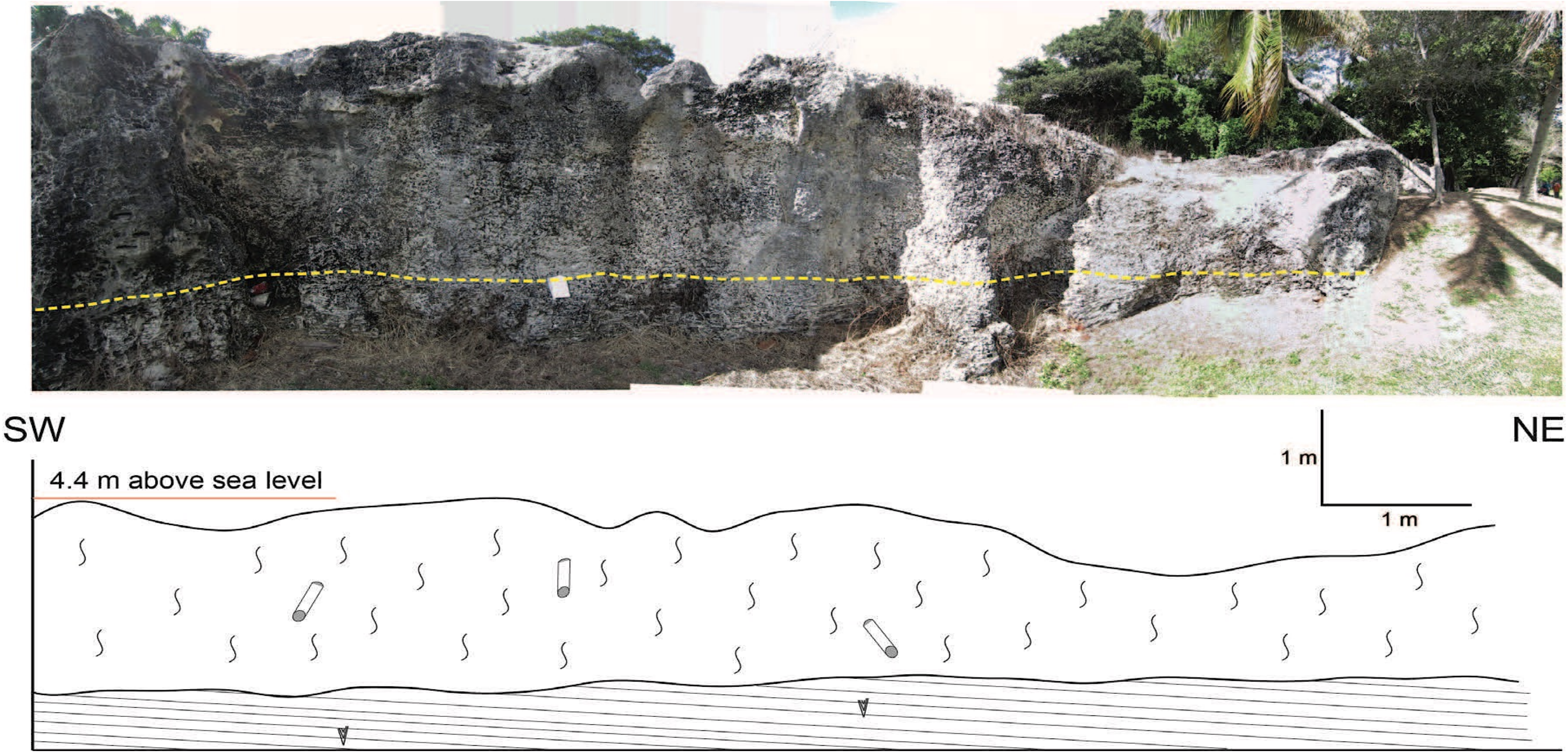


Depositional Facies – Cross Bedded



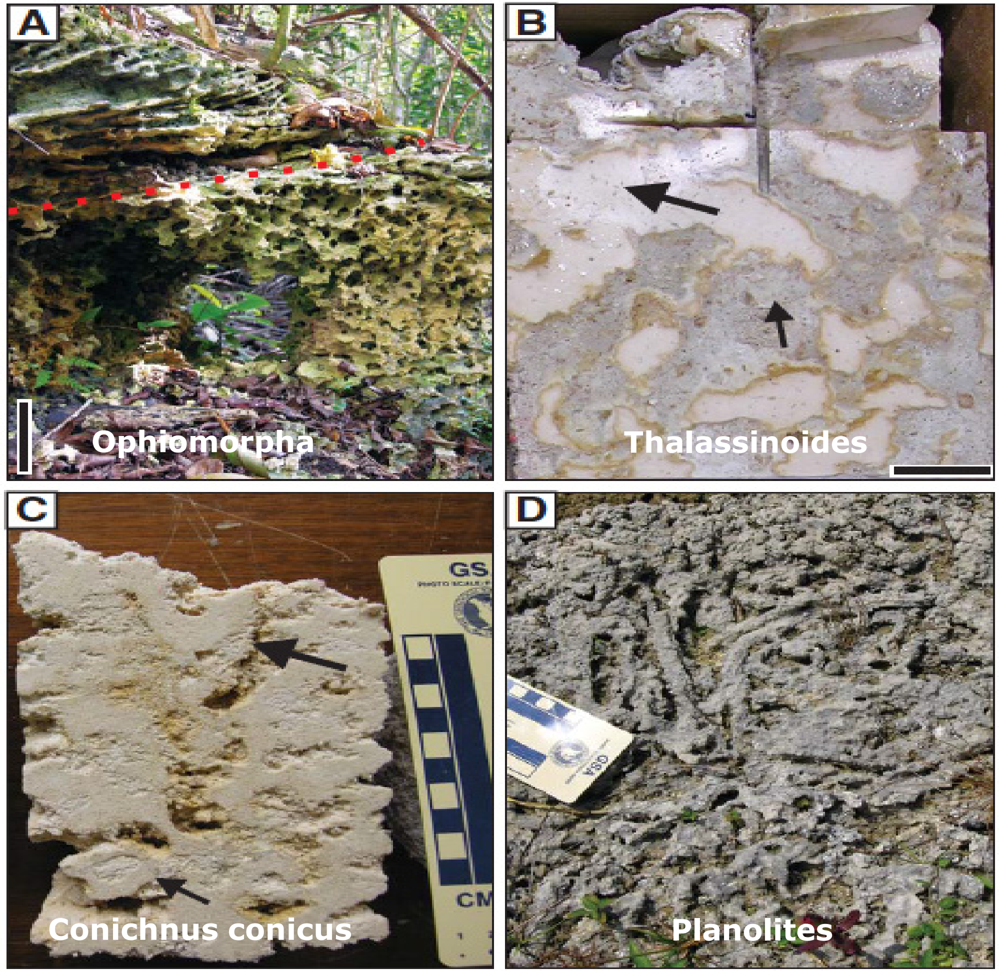
From Usdan, 2014

Depositional Facies – Burrowed, Relict Bedded



From Usdan, 2014

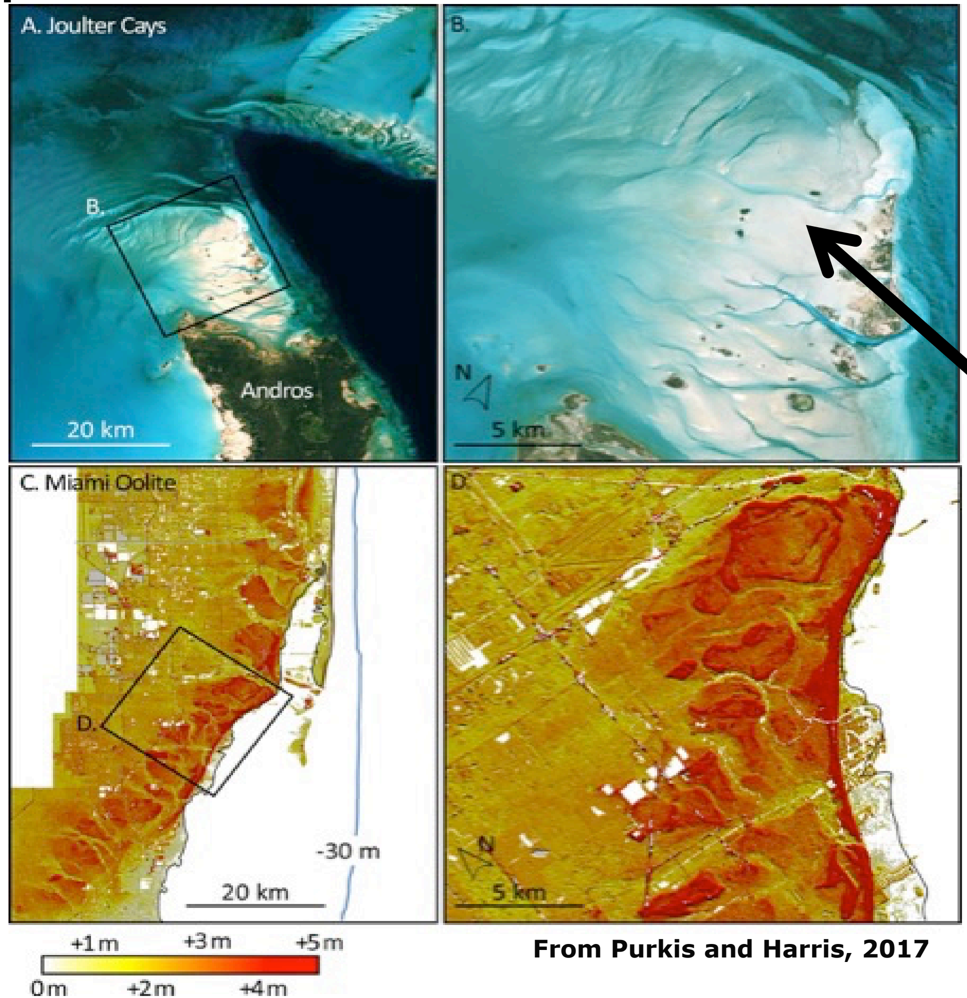
Depositional Facies - Burrowed



Major ichnofabrics
(burrow types)

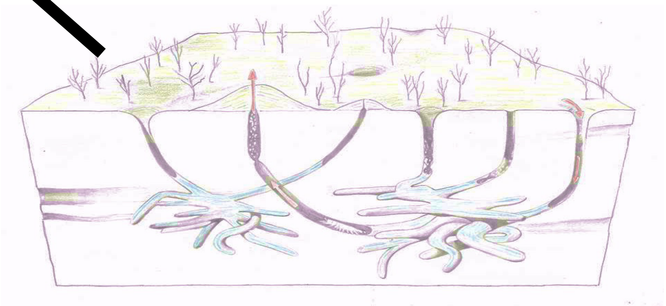
From Cunningham et al. (2009)

Depositional Facies - Burrowed



From Purkis and Harris, 2017

Thalassinidean shrimp
Callianassids



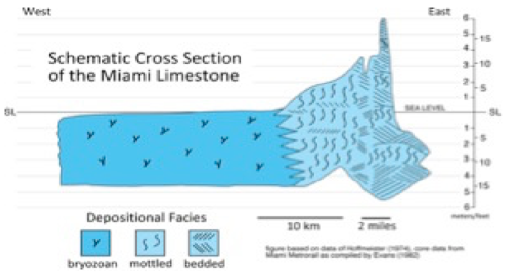
Burrow system
Ophiomorpha ichnofabric

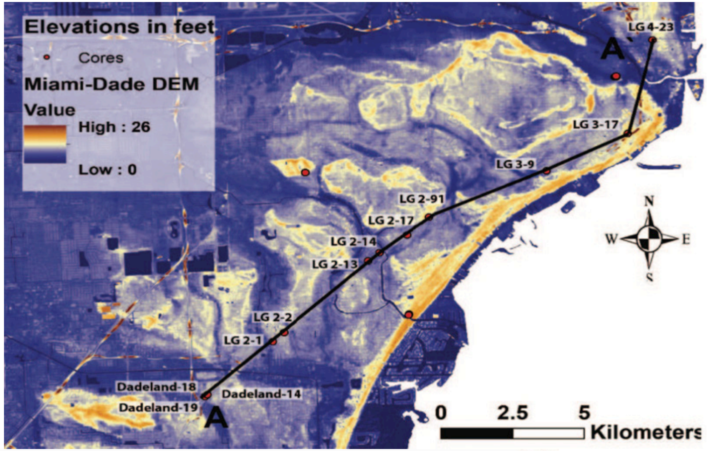
Depositional Facies - Burrowed

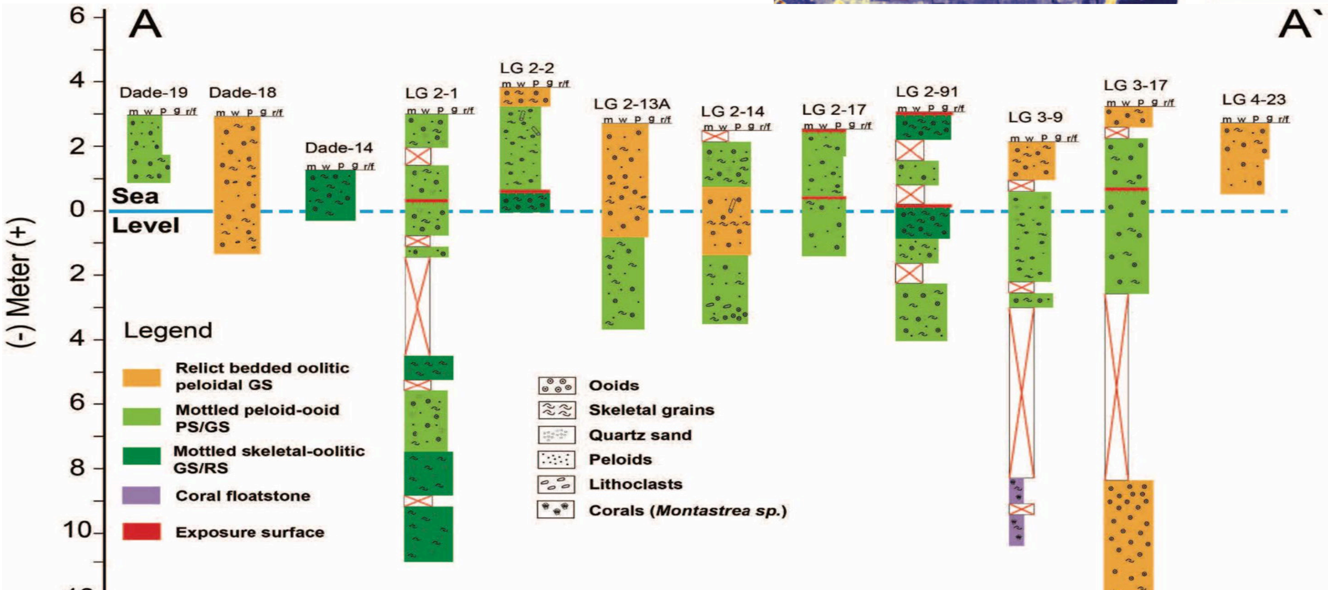
Vertical drone view from 100 m

(Courtesy of Juan Carlos-Laya)

Depositional Facies – Distribution

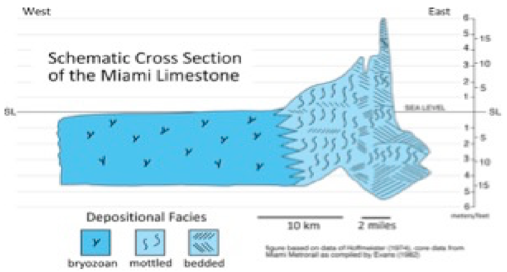


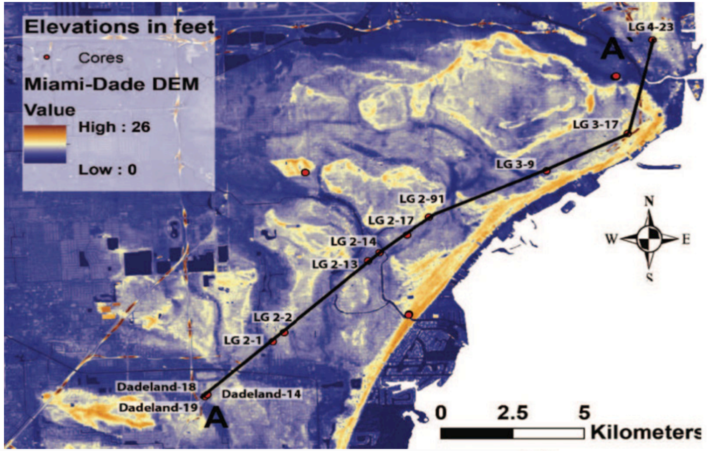


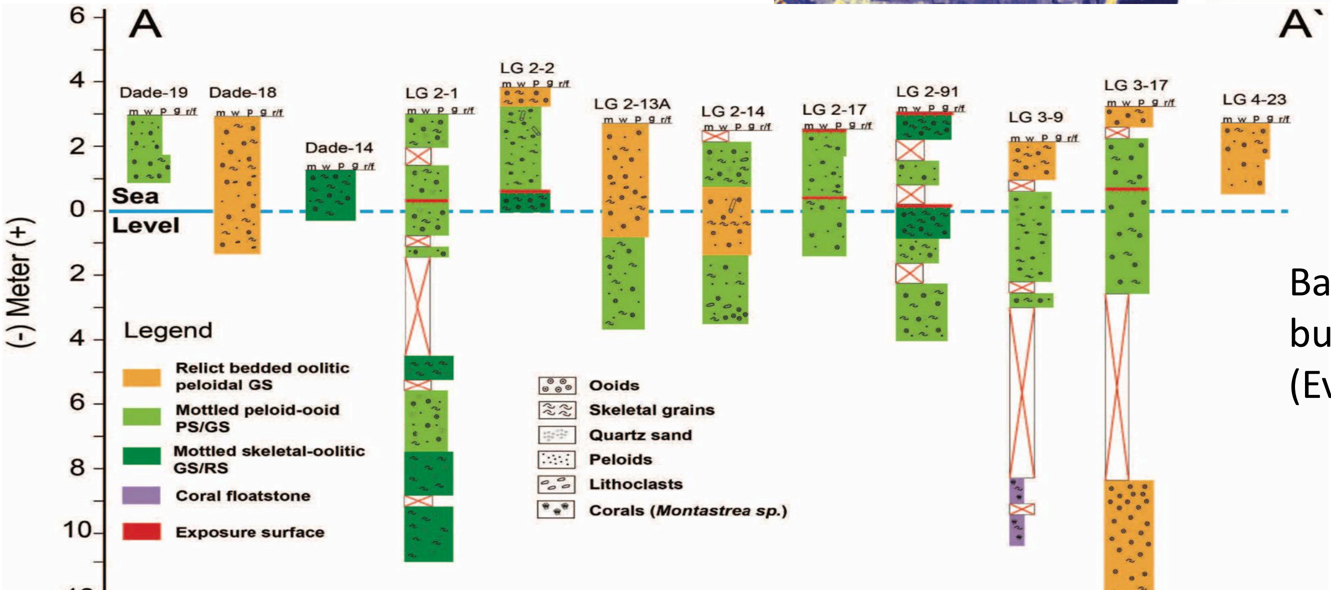


From Usdan, 2014

Depositional Facies – Distribution



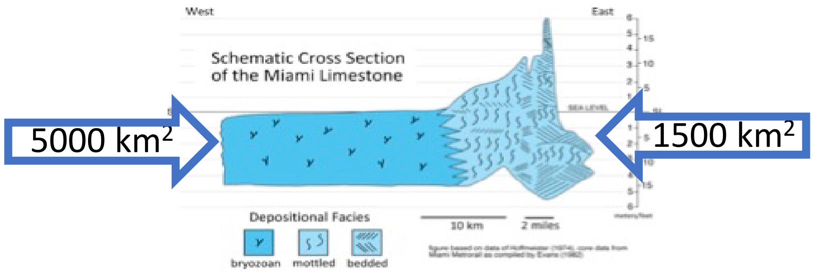


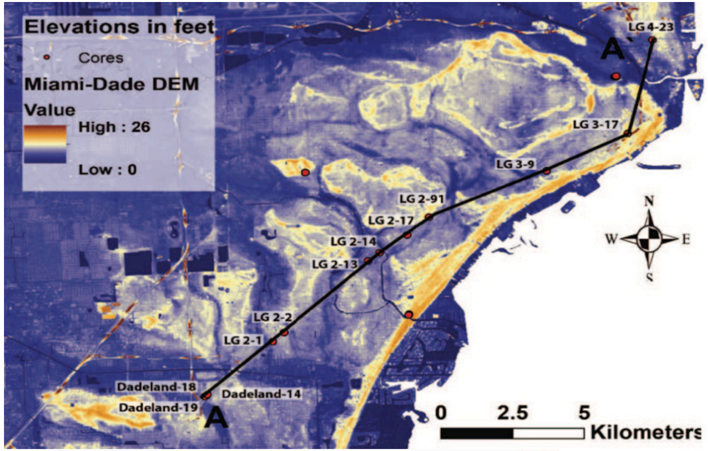


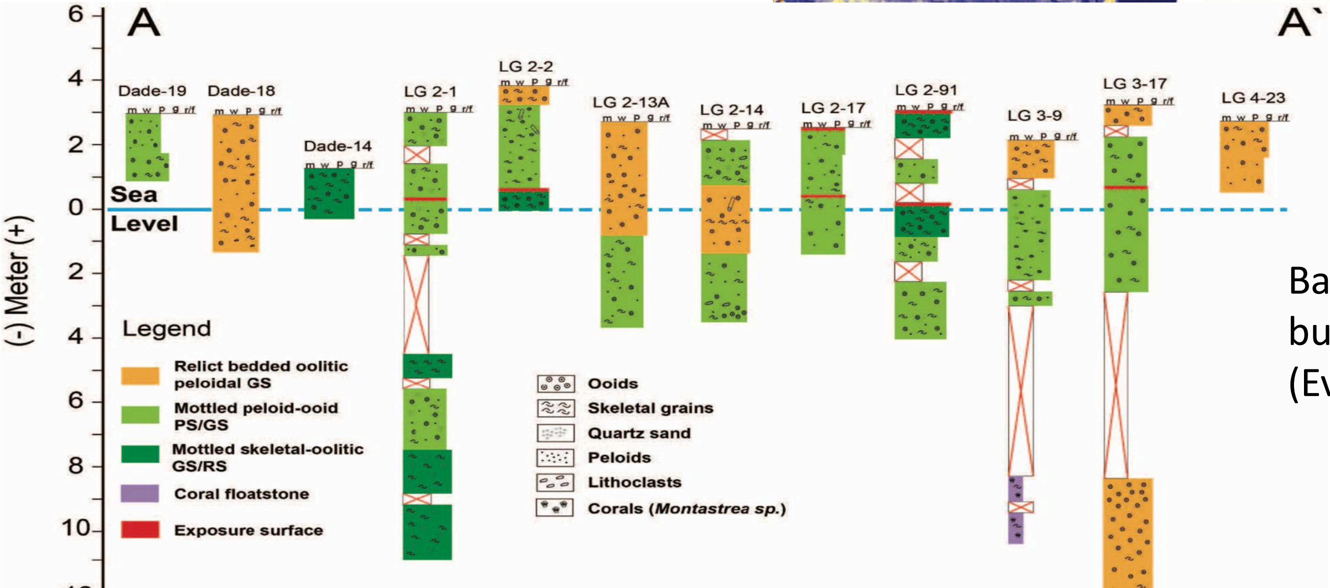
From Usdan, 2014

Barrier bar is 60% burrowed facies (Evans, 1982)

Depositional Facies – Distribution







From Usdan, 2014

Barrier bar is 60% burrowed facies (Evans, 1982)

Diagenetic Modification - Timing

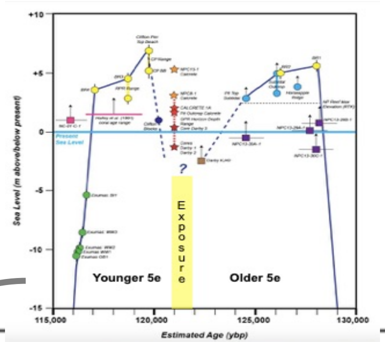
- Deposited during MIS 5e at sea-level >6m higher than today

- Subaerially exposed and undergoing meteoric diagenesis for >115 ka in a tropical climate

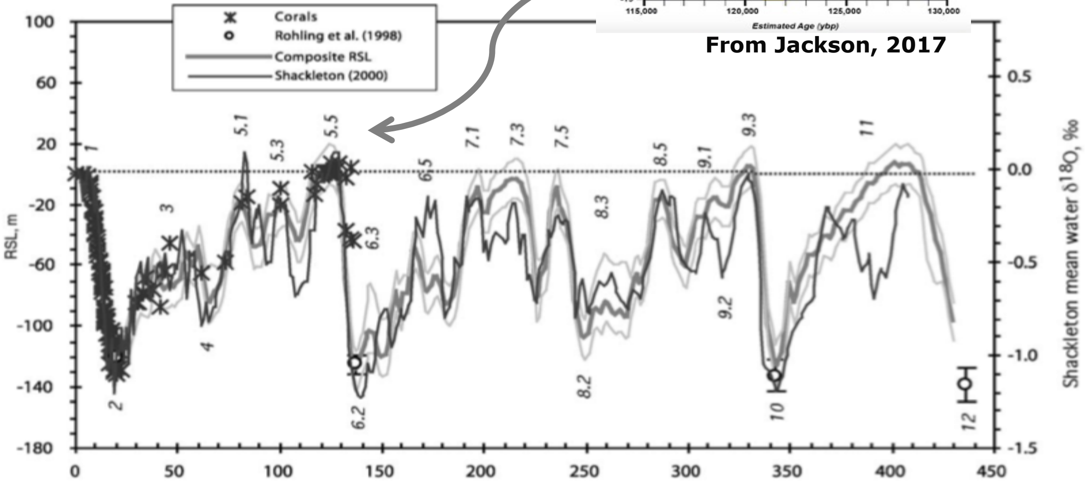
    Some degree of surface modification and general lowering (estimated to be ~1.5 m)

    Cementation, recrystallization, **dissolution**

    Overprint of surface karst (dolines) and shallow subsurface caves



From Jackson, 2017

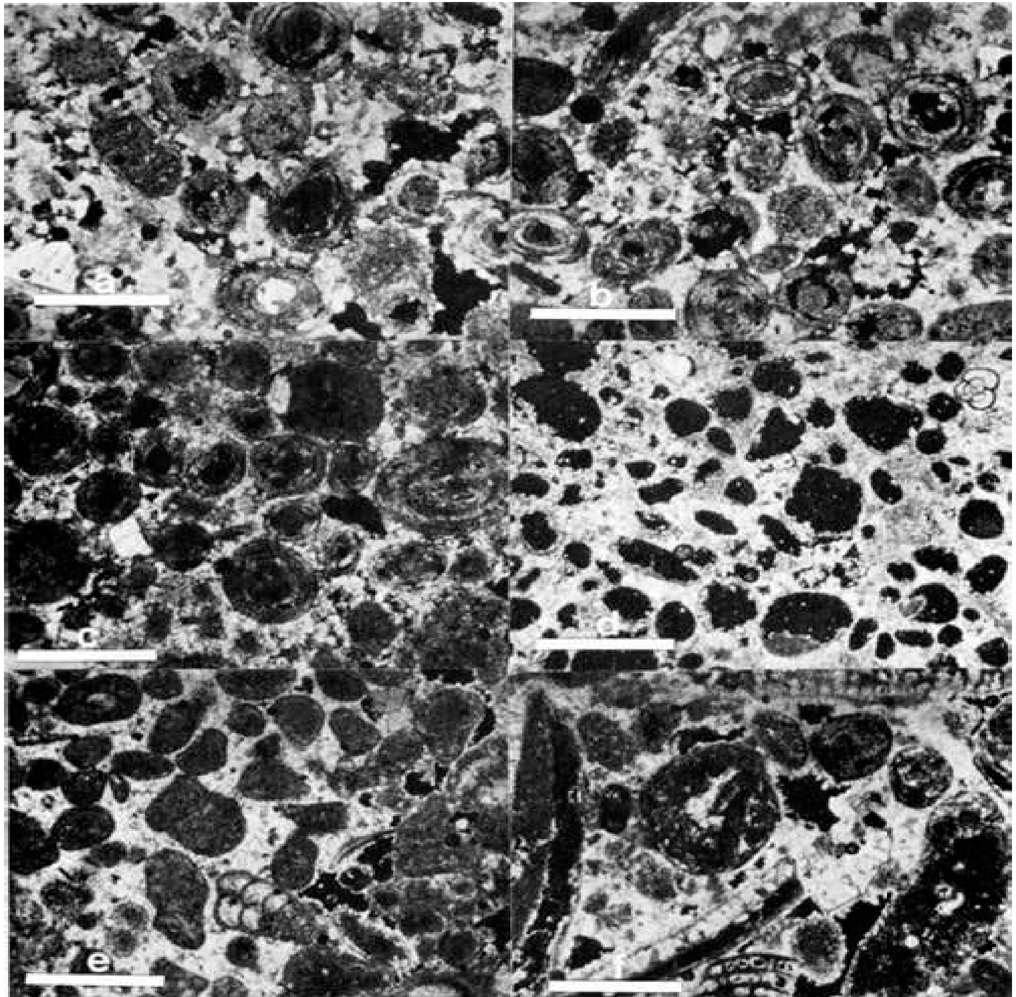


From Waelbroeck et al., 2002

Diagenetic Modification - Products

Ooid grst of tidal bar

Ooid grst of barrier bar



Ooid grst of barrier bar

Bryozoan facies W of ooid bars

Porosity 17-67%, ave. 43%

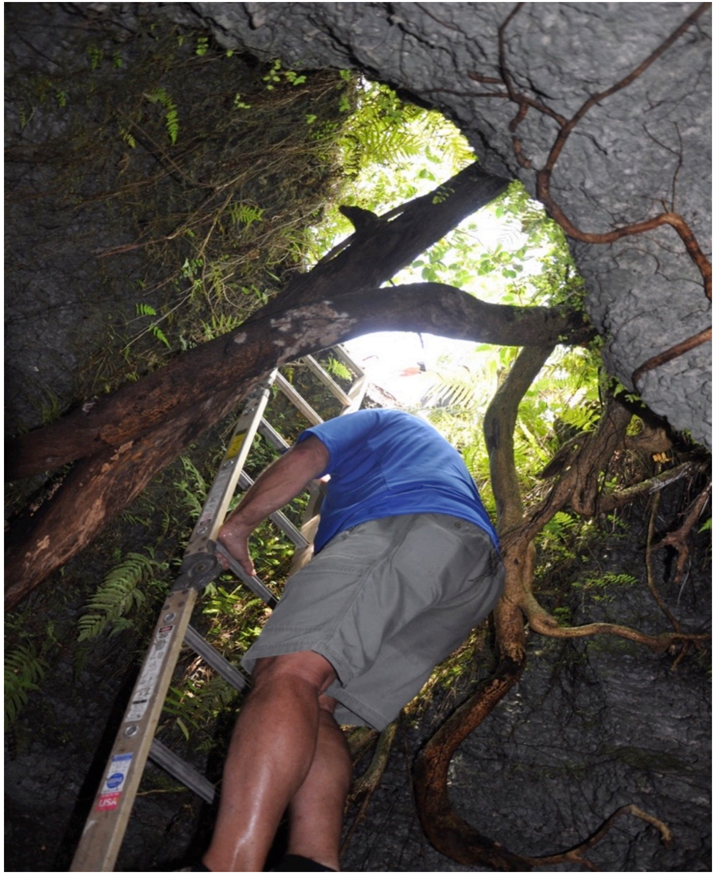
Permeability highly variable (10-30 Darcies!)

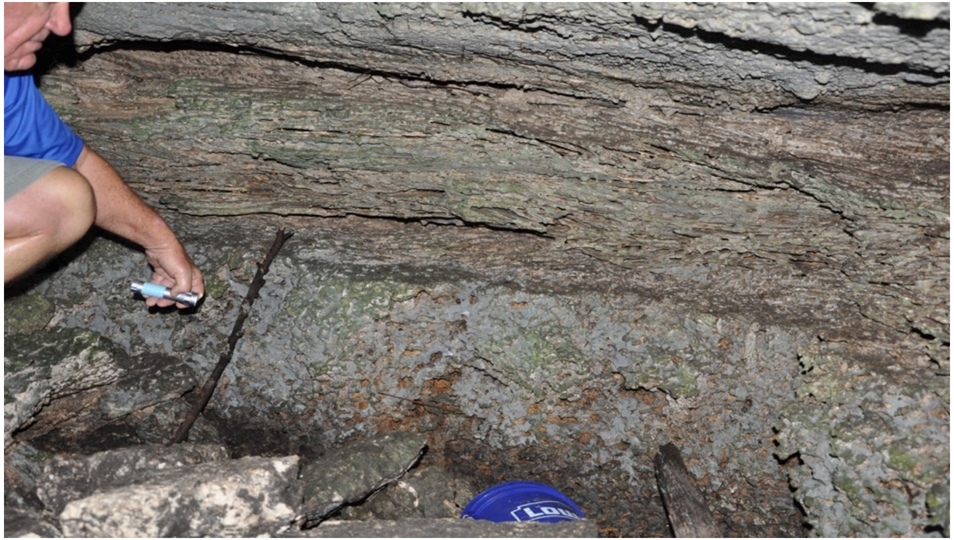
Peloid-skeletal grst E of barrier bar

Peloid-skeletal grst E of barrier bar

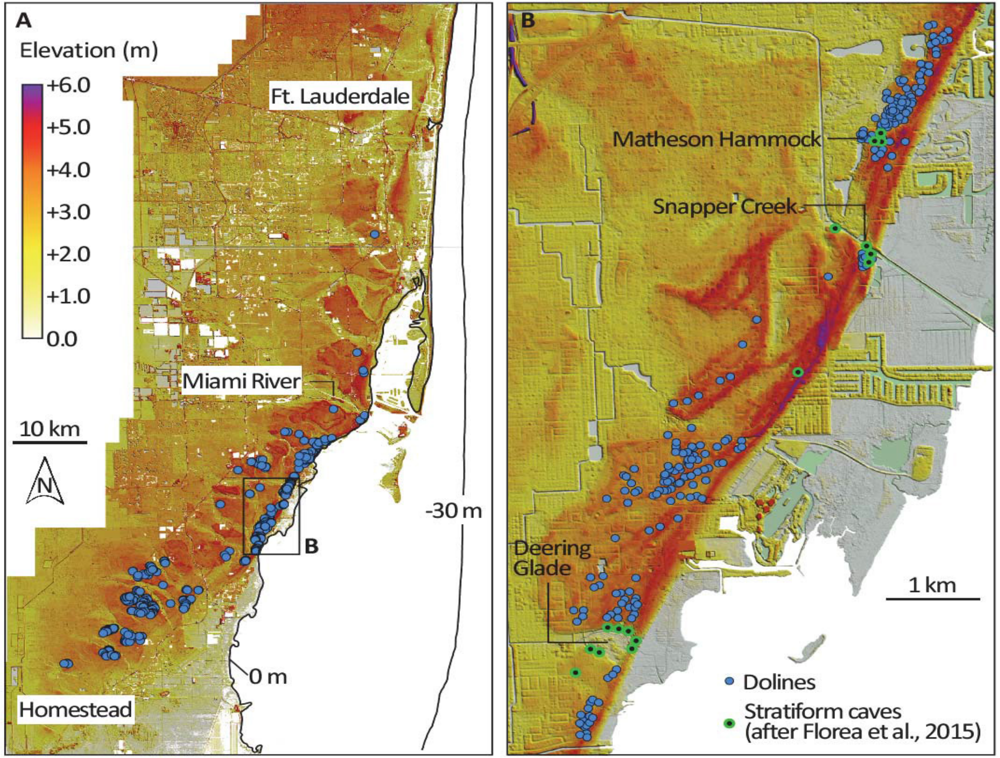
Dolines and Caves

Dolines and Caves





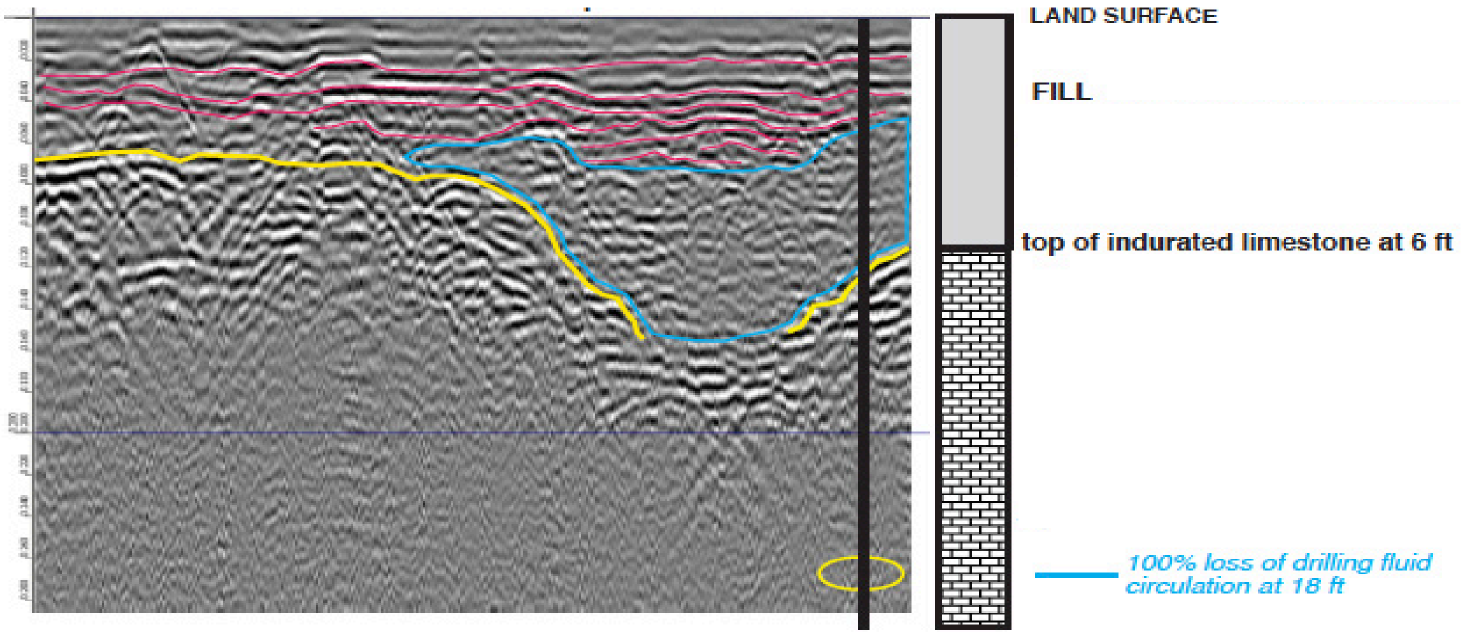
Diagenetic Modification - Surficial Karst Features



From Harris et al., 2018

- Dolines preferentially form in the barrier bar within troughs between linear sand ridges.
- Stratiform caves formed locally along the edges of paleo-channels cutting through the barrier bar
- Preliminary interrogation suggests these features are widely separated, so **excess permeability added by the karst features is questionable but warranted further study.**

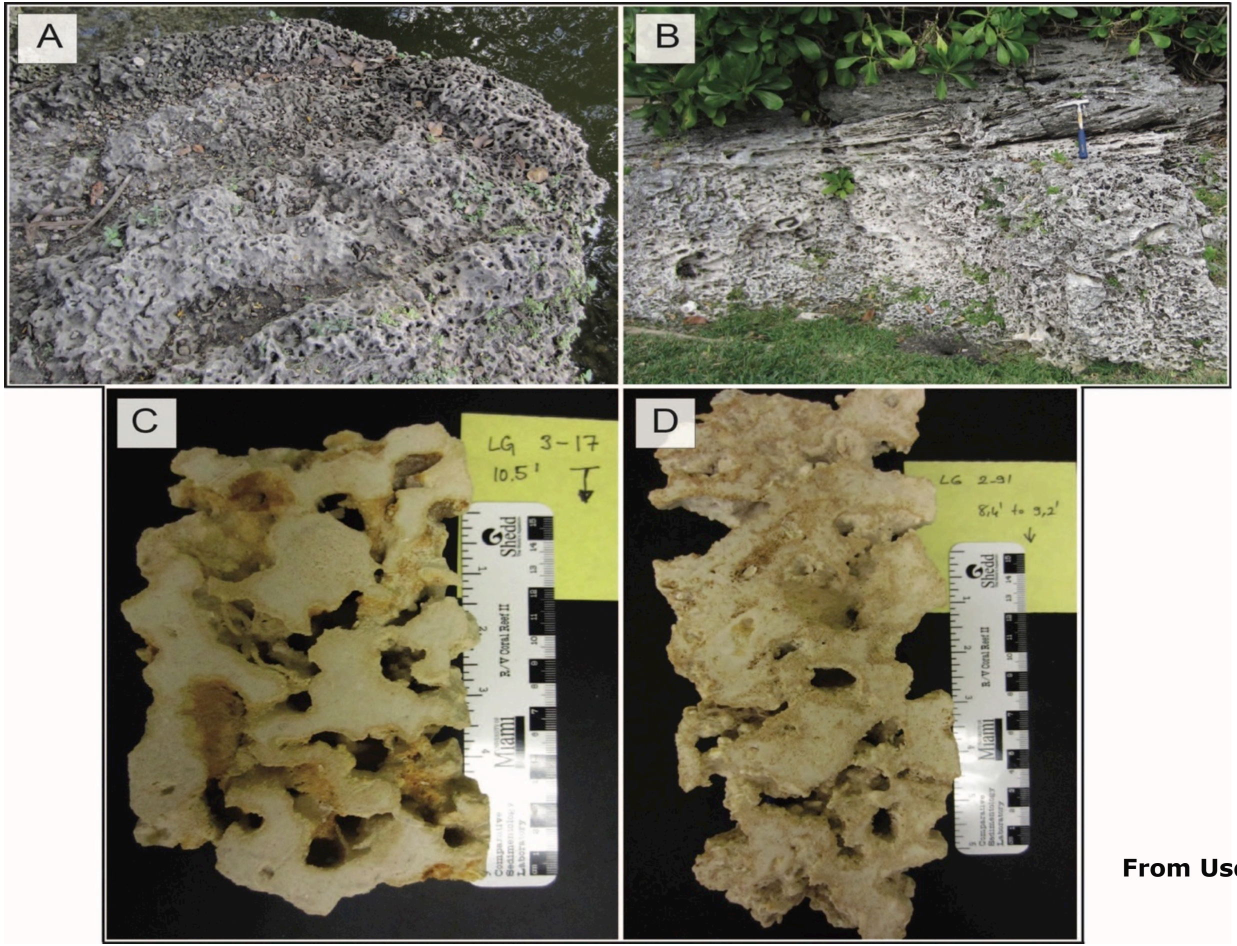
Surficial Karst Features – GPR and LCZ



From Don McNeill, Pers. Comm.

LCZ, but why?

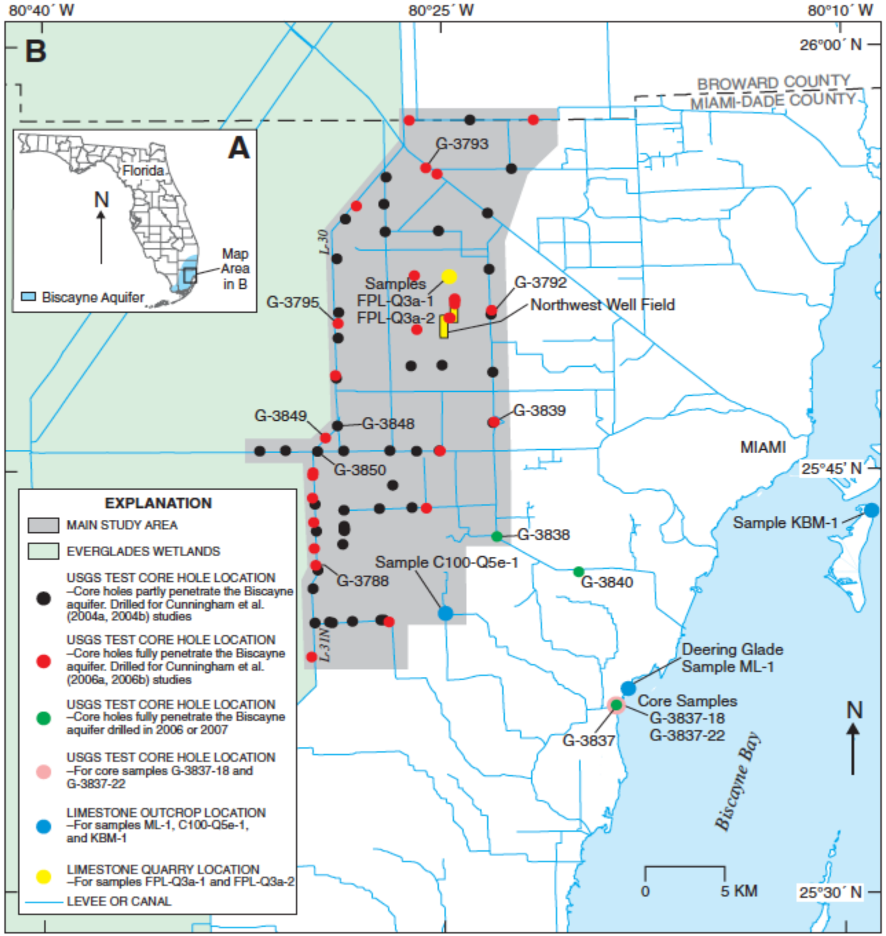
Dissolution of Burrowed Facies



From Usdan, 2014

Touching Vug Macroporosity

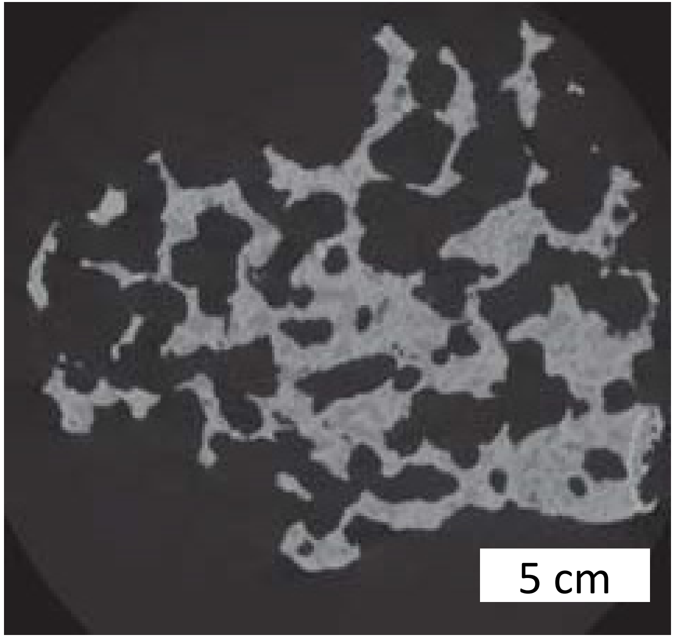
Biscayne Aquifer – Subsurface Data Set



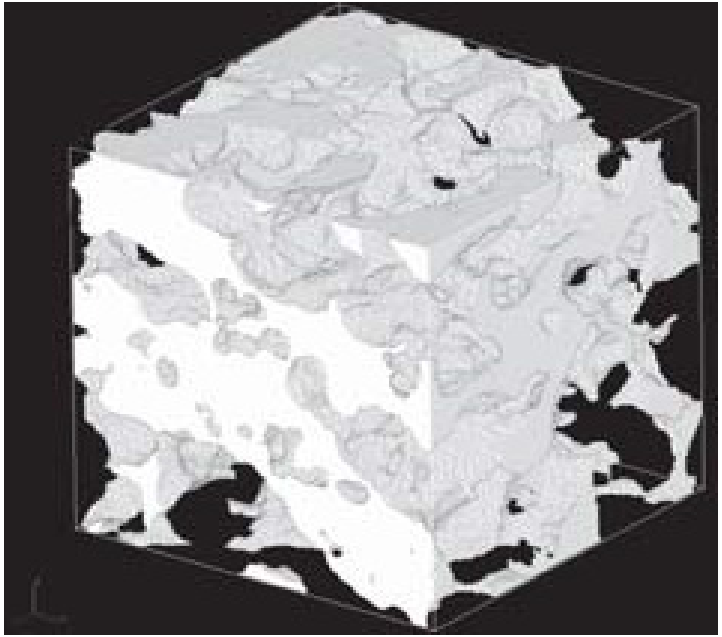
- Miami oolite is the uppermost portion of the Biscayne Aquifer, a highly transmissive unconfined aquifer providing the bulk of potable water for the region
- More regional understanding of fluid flow through the deposit sheds valuable insight to our analysis of the larger-scale permeability patterns and reservoir implications of facies and diagenetic overprint

From Cunningham et al., 2009

Touching Vug Macroporosity = Por/Perm



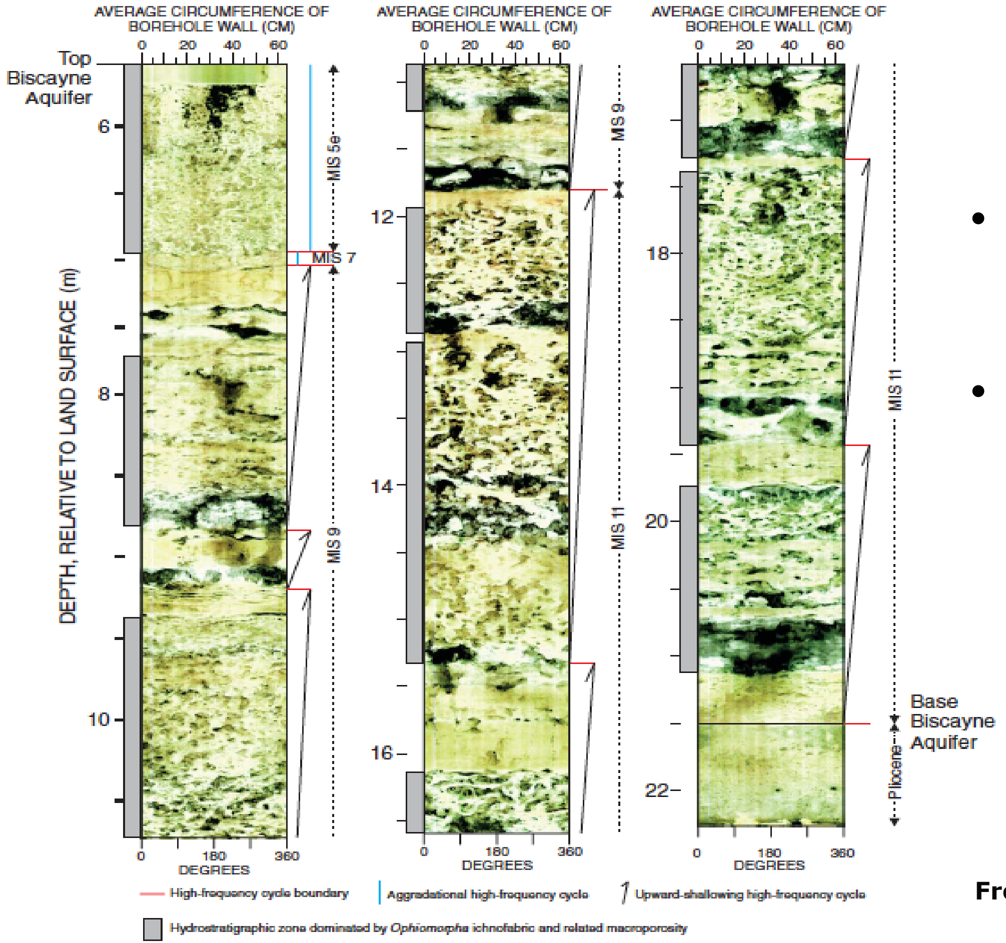
X-ray CT Scan
Ooid-peloid Grst-Pkst



Volume Rendering
Calculated macroporosity = 50%
Vertical hydraulic conductivity = 34.6 m/s
(~ 3.5 x 10^6 Darcies)

From Cunningham et al., 2009

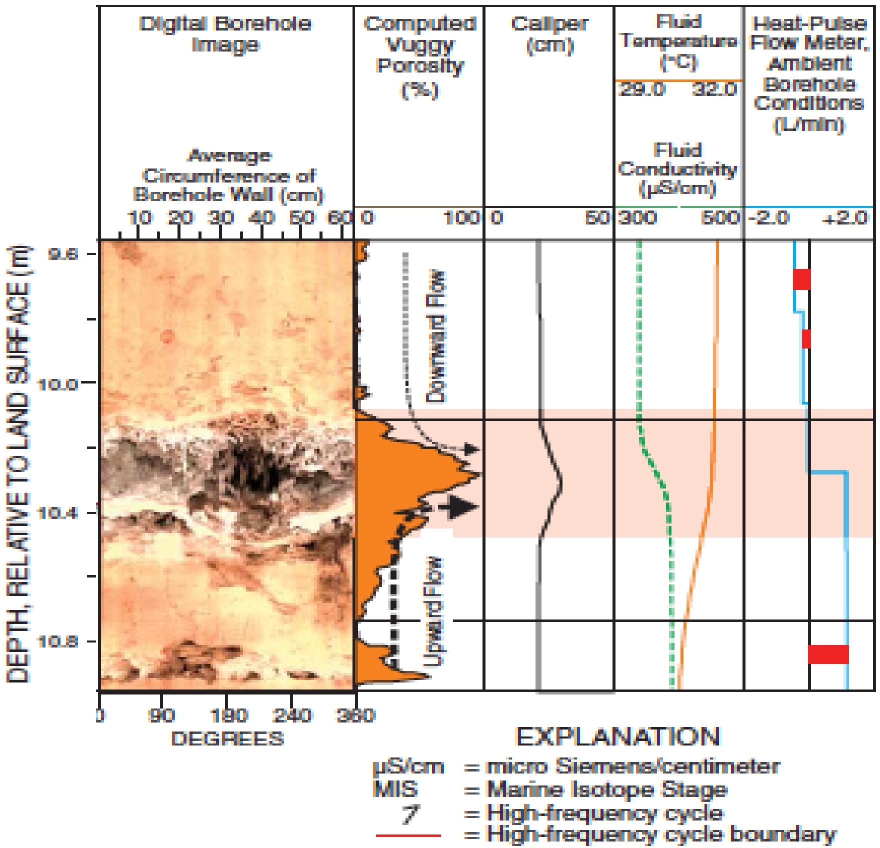
Touching Vug Macroporosity is Abundant



- Matrix porosity (interparticle and separate vugs)
- Touching-vug macroporosity associated with burrowed [Ophiomorpha] intervals = gray bars

From Cunningham et al., 2009

Touching Vug Macroporosity = High Flow

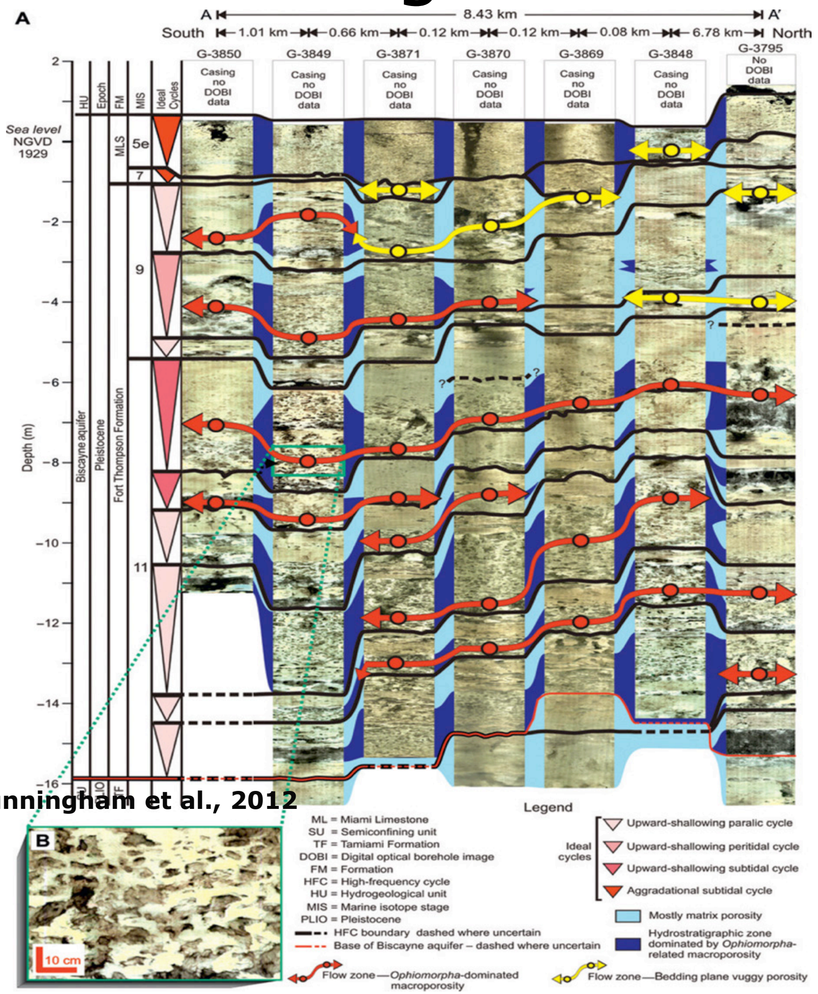


Well and flow test data show:

- Matrix porosity provides most of the groundwater storage
- Various types of touching vug macroporosity provide the groundwater flow

From Cunningham et al., 2009

Stratiform High Permeability Zones



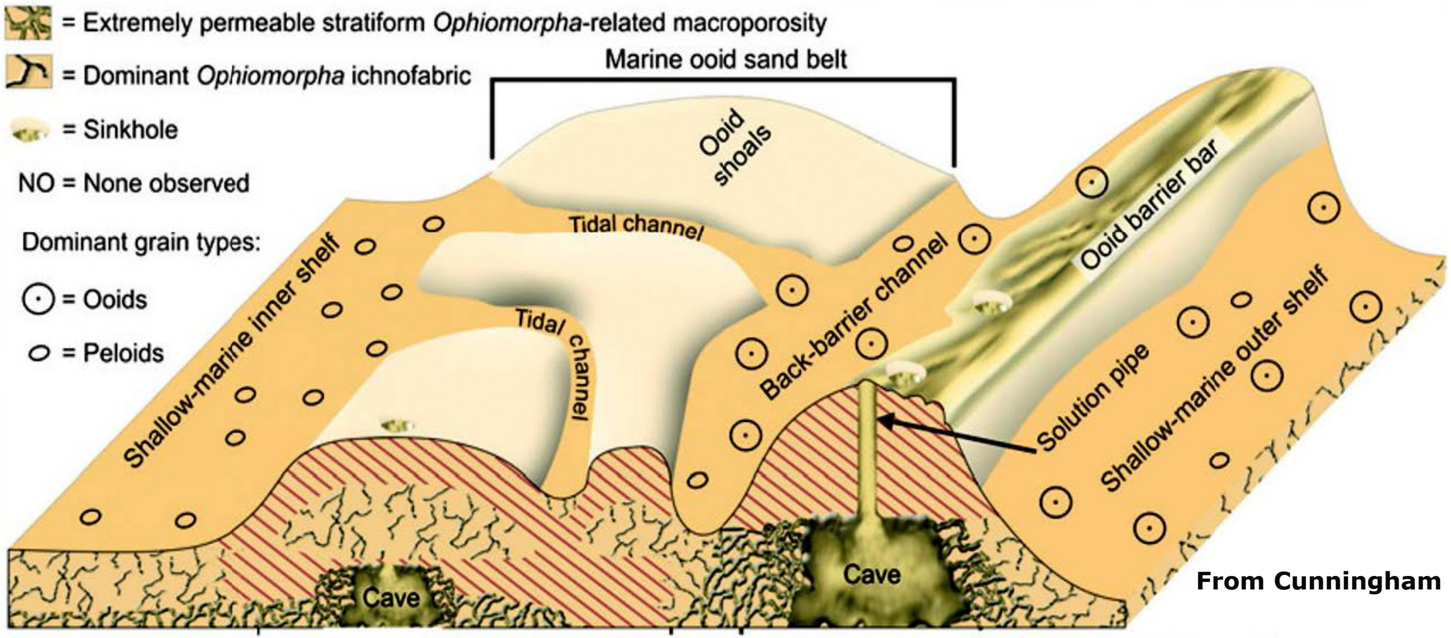
From Cunningham et al., 2012

Touching-vug macroporosity and high-flow zones:

- Are stratiform, aerially extensive high-permeability zones ("super k" zones) associated with burrowed intervals
- Not from "connected" caves and dolines

"Measurements (geophysical, tracer, temperature) across 64 flow zones in 16 boreholes indicate that ichnogenic macroporosity is the principal pore type in groundwater flow zones … only a single cavernous-sized flow zone was identified."

~2–5 orders of magnitude higher flow than the "super-K" zones of Ghawar field, Saudi Arabia



From Cunningham et al., 2012

Relations between:

a) the depositional elements of the Miami oolite (barrier bar, shoals-channels),
b) localized occurrences of dolines and stratiform caves, and
c) widespread distribution of burrowed intervals and Ophiomorpha-related macroporosity.

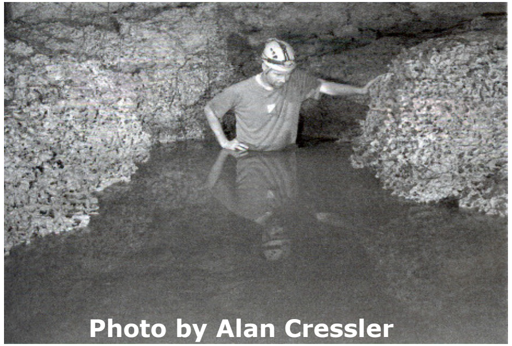


Photo by Alan Cressler

Key Findings

- The Miami oolite illustrates that a particular depositional facies (burrowed intervals) directed early-stage dissolution (creating touching-vug macroporosity) to produce stratiform high-permeability zones that dominate flow at the larger scale.

- It is hypothesized that the burrow-related porosity provided early preferential pathways for groundwater and concentrated dissolution, resulting in a **reservoir-analog super k zone**.

- A profound implication for analogous grainy and karsted reservoirs (eogenetic karst) is that a **fundamental understanding of depositional facies variation remains critical** for characterizing reservoir quality and performance despite the diagenetic overprint.